

How Much Trabecular Bone Damage Is Induced By Screw Insertion?

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INTRODUCTION

Osteoporosis is becoming more and more prevalent due to the constantly ageing population. People suffering from osteoporosis have a greater risk for bone fractures. At the same time, treatment outcomes are negatively affected; e.g. complications such as bending, backing-out and screw cut-out have been reported as high as 41% for fracture fixation of the proximal femur [1]. It has been shown that such complications are related to the inferior osteoporotic bone quality [2, 3]. Yet, a detailed understanding of how trabecular microstructure affects screw fixation is still lacking. Furthermore, it is unclear how screw fixation is affected by bone damage occurring during the process of screw insertion. In order to address this question, the aim of this study was to visualize, localize and quantify the amount of peri-implant bone damage induced by screw insertion.

METHODS

Five cylindrical trabecular bone specimens (16 mm height; 16 mm diameter) were taken from five cadaveric human femoral heads. After predrilling, a titanium screw (2.7 mm diameter, 17.7 mm length) was placed in the centre of each specimen according to the manufacturer's guidelines. All specimens were scanned twice with micro-computed tomography (μ CT50, Scanco Medical, Brüttisellen, Switzerland) at a nominal isotropic resolution of 20 μ m; once just before and once just after screw placement. After reconstruction, rigid image registration was performed [3] to align the two images, after which the segmented screw from the post-insertion scan was inserted digitally into the image of the pre-insertion scan. Image overlay was performed between the physically inserted (PI) screw model and the digitally inserted (DI) screw model. In the overlay image voxels were classified as belonging to (1) screw, (2) bone present in both images, (3) bone present in one of the images only, (4) bone marrow. Bone offset volume (BOV) was defined as all voxels belonging to category 3. Bone off-set density (BOD) was assessed in hollow cylindrical volumes of interest (VOI) around the screw ranging from 0.0-5.4 mm in steps of 0.6 mm by computing the bone-off-set volume (BOV) normalized to the total volume (TV) of the corresponding cylindrical VOI ($BOD = BOV/TV$). The accuracy of the entire rescanning and registration procedures was assessed by computing the bone off-set in a volume of interest (4.2 mm height, 5.4 mm diameter) underneath the screw because no architectural changes were expected here.

RESULTS

The scanning and registration procedure was successful in all 5 cases (Fig. 1). BOV/TV in the volume of interest underneath the screw was 4.0% (range 3.2%-5.8%). BOV/TV close to the implant was substantially higher (range 12.2%-16.8%; Fig. 2), indicating insertion-related bone damage. With increasing distance from the screw BOV/TV quickly converged towards the 4% residual error value found in the (unaffected) volume underneath the screw. Significant changes in BOV/TV were found up to 2.4 mm away from the screw (Fig. 2).

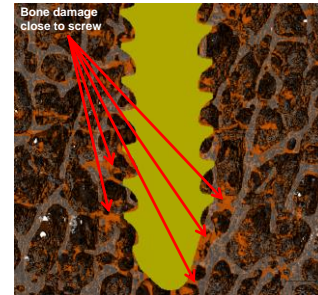


Fig. 1: μ CT image of bone damage in peri-implant region. Yellow: screw; Gray: intact bone; Orange: off-set bone. More bone damage can be found close to the implant.

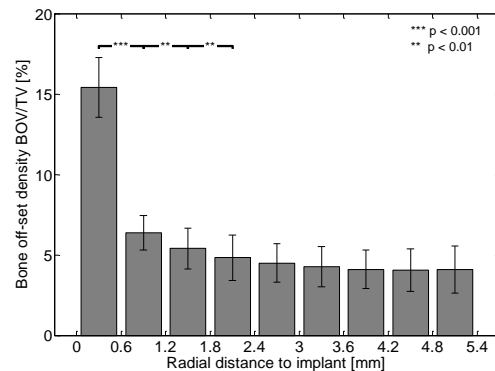


Fig. 2: Bone off-set density (BOV/TV) plotted against the cylindrical VOI shows significant changes up to 2.4 mm away from the implant.

DISCUSSION

We developed a technique to visualize, localize and quantify trabecular bone damage produced by screw insertion. The registration error of 4% is small enough to serve as a threshold to detect bone damage accumulation consisting of trabecular bone deformation and bone debris due to screw insertion. We demonstrated that for this particular screw, screw insertion induces peri-implant bone damage up to 2.4 mm away from the screw; this corresponds to 4 times the screw thread size. We hypothesize, that the screw thread design is a critical determinant for the size of the peri-implant region affected by bone damage.

SIGNIFICANCE

A technique has been designed and implemented to quantify and localize the amount of bone damage induced by screw insertion. This method can be helpful in developing less invasive screw designs, especially for osteoporotic bone. Furthermore, we expect that this will further our understanding on screw stability in (osteoporotic) trabecular bone.

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